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Virginia Remote Sensing Device Study
Addendum – Vehicle Opacity

Prepared for:

Virginia Department of Environmental Quality

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1. Introduction

The RSD4000 reports a smoke related measurement called a SMOKE FACTOR. The Smoke Factor is proportional to the ratio of particulate mass in the exhaust to the fuel use rate.

The visibility of exhaust particles depends on the number, composition and size of the particles and the wavelength of light used to observe the particles. Classical smoke meters use longer wavelength “green” light (sometimes “red”) spectral frequencies. Since “green” light has a wavelength of ~550 nm, particle sizes that are much smaller than 550 nm will be practically invisible (very little light attenuation) to the instrument. Hence, if a large percentage of the diesel smoke particles are much smaller than 550 nm, the classical smoke meter will not sense them. Unlike classical smoke meters, the RSD4000 Smoke Factor measures opacity in the 230 nm UV spectral range. This wavelength provides for much better sensitivity and linearity in sensing the small diesel particles produced by today’s diesel engines. Old diesel technology engines produced particle sizes mostly larger than 550 nm (mass peak at ~1500nm). Newer •diesel technology, since the early 1980’s, produces diesel particle sizes mostly less than 550 nm (mass peak at ~250 nm (PM 2.5)). The RSD measurement using UV light (~230 nm) is therefore is quite sensitive to the smoke particle sizes produced by today’s diesel.

In addition to the greater sensitivities using UV wavelength, the RSD Smoke Factor calculation also relates the mass of particles to the amount of fuel burned. This is achieved by simultaneously measuring the concentrations of carbon-based exhaust constituents (CO_2, CO, and HC’s). This capability allows for easier quantification of the particle inventory. Classical smoke meters will reduce their opacity result as excess air is added to the exhaust (e.g. increased RPM or turbo-charging) even though the amount of particulate output is constant.

For diesel black smoke a Smoke Factor of 1 indicates that 1% of the fuel is unburned particulate mass in the exhaust. The unit has not yet been calibrated for other types of smoke and results for gasoline vehicles are therefore only approximate for gasoline vehicles.

Presentations and other references to Smoke Factor in the RSD4000 include:

“Smoke Measurement Development Status for Remote Sensing” presented at CRC Conference April 16, 2002

“Practical In-Use Testing of Diesel Engines” ESP presentation at Clean Air Conference September, 2002

The RSD4000 was evaluated in the British Columbia ‘Aircare’ program, which is one of the few programs measuring light duty diesel smoke under loaded mode conditions. Units were set-up at two inspection stations; one on an entrance driveway and one in the parking lot. 156 comparison tests were run resulting in 25 I/M lane failures (opacity>30) and 32 RSD4000 failures (smoke factor>1). Of the 32 RSD4000 failures, 16 failed in the I/M lane and 16 did not. But the 16 vehicles that passed in the lane and failed the RSD4000 were generally visibly smoky. An example of a vehicle that fast-passed in the lane is shown in Figure 1-1.

Figure 1-1 Example of a Vehicle Passing I/M that failed the RSD4000 Inspection

Measurement of Heavy Vehicles

To make smoke measurements (or any measurement) the instrumentation must place the beam path where the exhaust exists in sufficient concentrations to be measured. For low, side-exhaust heavy-duty diesel trucks this generally means that the instrumentation must be deployed at very low levels under the cargo-carrying portion of the vehicle. In this area there are many possible obstructions to the measurement beam. Special filtering and measurement techniques are required to properly reject the effects of these obstructions so as not to misinterpret a physical obstruction as opacity. ESP has successfully demonstrated this measurement capability. Placement of license plates relative to the exhaust tailpipe varies more widely on heavy trucks than on passenger vehicles. This reduces the truck identification rate. Heavy trucks are consequently under-represented in the results.

To measure heavy trucks with vertical exhausts, RSD equipment must be deployed at a height that captures the trailing exhaust plume from the top of the exhaust pipes. This was not an element of the Virginia study; therefore, results for vehicles with vertical exhausts are not included.

2. Smoke Emissions vs. VSP

Figures 2-1 shows the relationship between smoke and VSP in gasoline vehicles. Smoke levels are much higher in vehicles over ten years old and tends to increase at high power. Figure 2-2 shows the results for diesel vehicles. Note the change in scale between the two charts. Individual diesel vehicles produce from three to ten times more smoke per unit of fuel than a gasoline vehicle. But since gasoline vehicles far outnumber diesels, the greater proportion of light vehicle PM inventory comes from gasoline engines.

Figure 2-1: Smoke Factor vs. VSP in Gasoline Vehicles

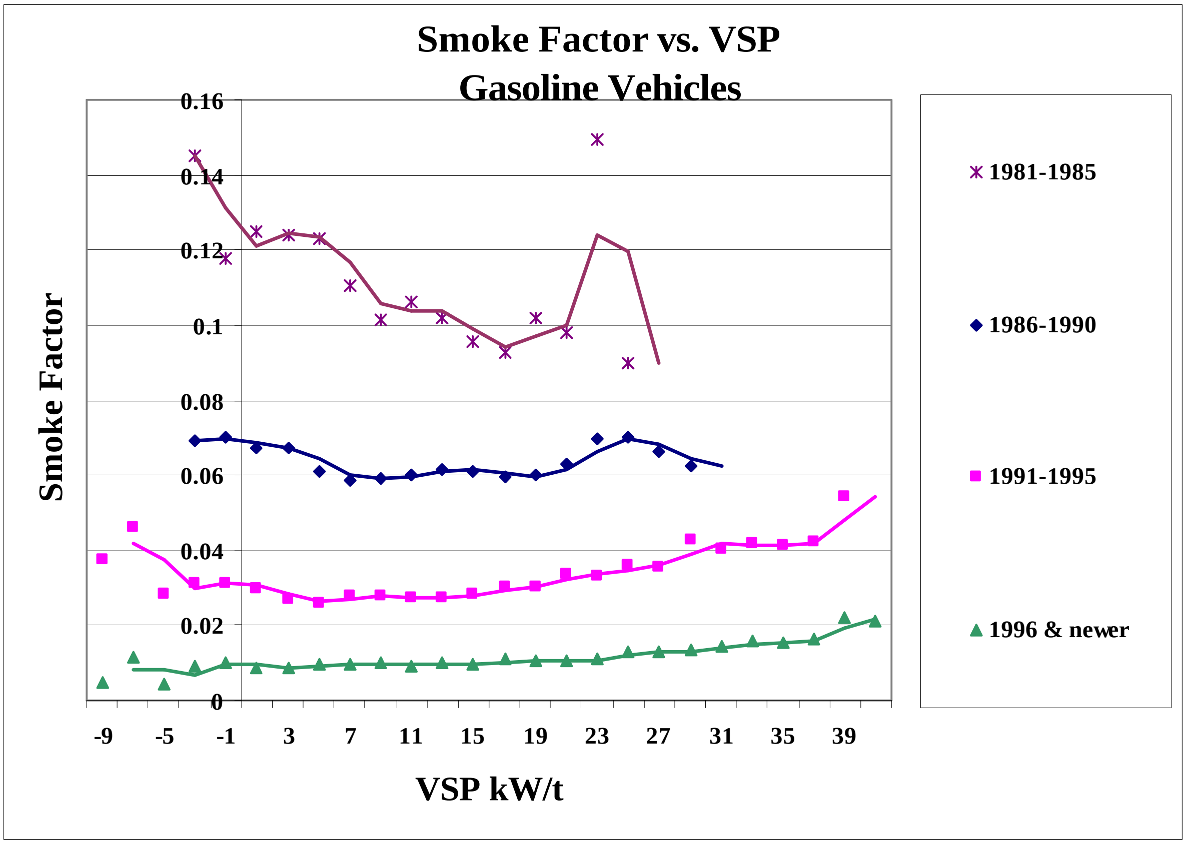
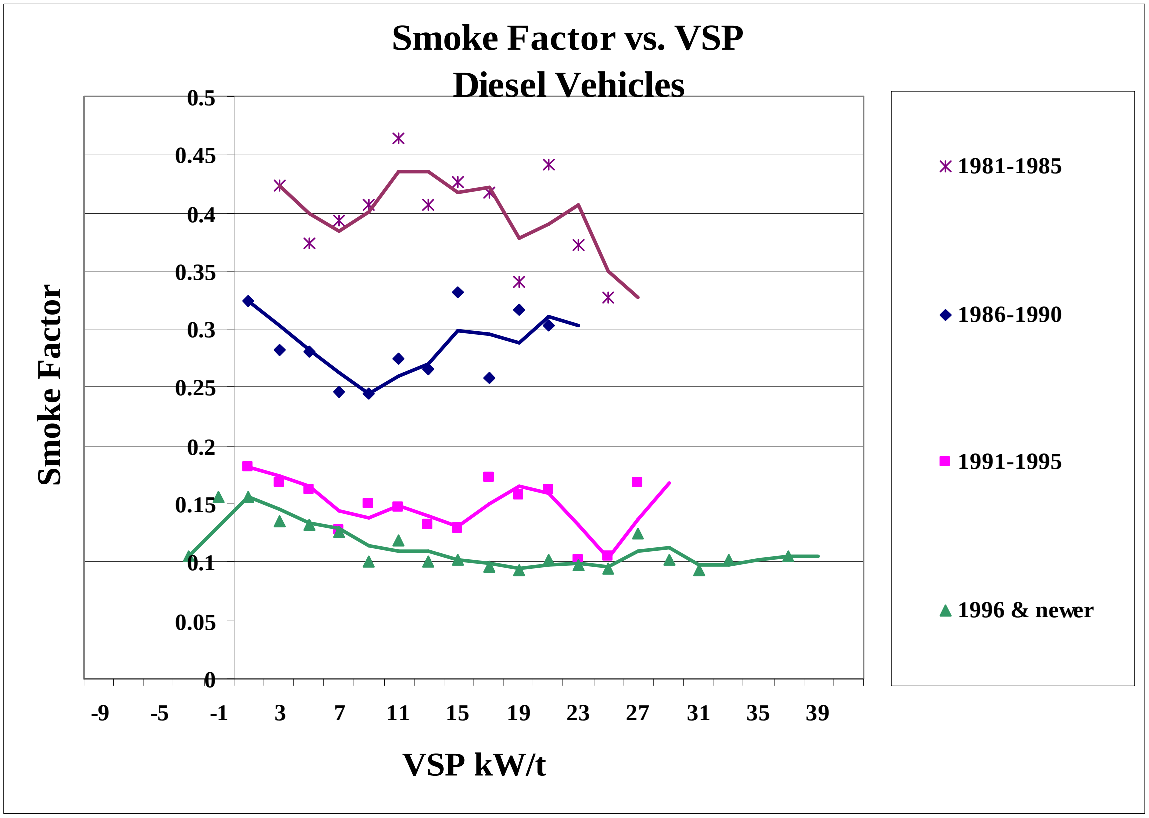


Figure 2-2: Smoke Factor vs. VSP in Diesel Vehicles



Smoke measurements were selected for analysis using the same criteria as the other pollutants. Collection hours with more than 5% of 1996 & newer vehicles having HC emissions in excess of 300 ppm were excluded, only measurements within a VSP range of 3-22 kW/t were included and day-to-day emissions were adjusted. Figures 2-3 and 2-4 show a sample of the day-to-day variations. These movements were six times larger for unit 4002 than 4001. The average daily offset for unit 4001 was 0.0032 vs. 0.0179 for 4002.

Figure 2-3: Day-to-day Smoke Factor 1999 & Newer Vehicles – Unit 4001

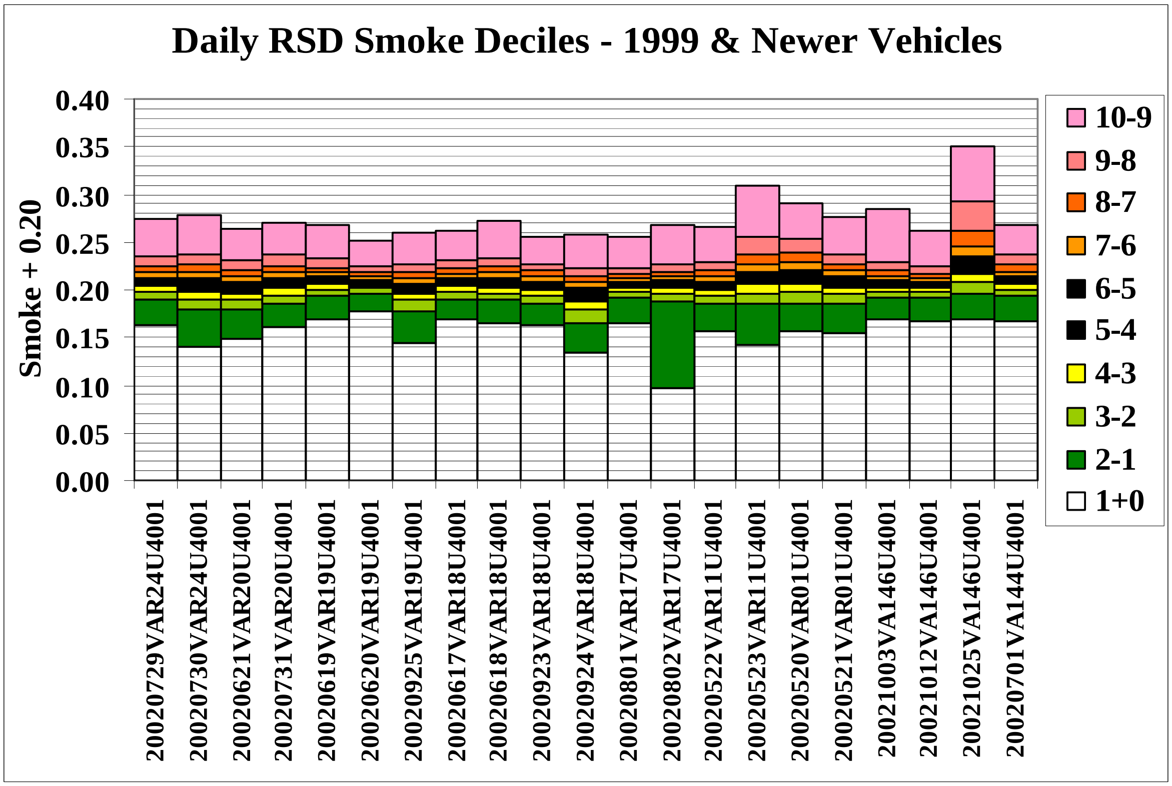
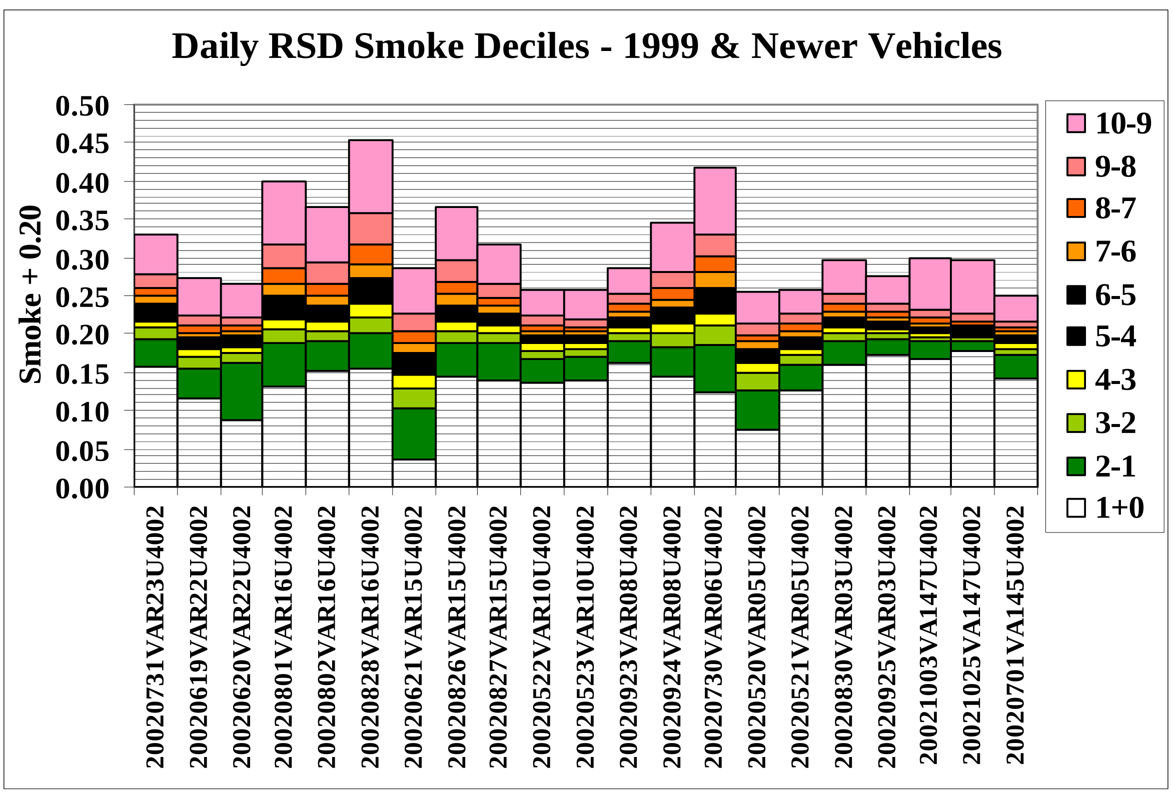


Figure 2-4: Day-to-day Smoke Factor 1999 & Newer Vehicles – Unit 4002



3. Smoke Emissions by Model Year

The distribution of gasoline and diesel vehicles measured in Northern Virginia is shown in Figures 3-1 and 3-2. Gasoline and diesel vehicle fuel type was decoded from each vehicle VIN and diesel vehicles were determined to be 0.8% of on-road measurements. In these figures the y-axis shows the percentage of all remote sensing measurements (both gasoline and diesel) identified for the model year. There are 1,961 diesel measurements and 246,673 gasoline vehicle measurements included in the charts. The percentage of diesel vehicles measured in the on-road fleet is small and is probably not fully representative of the diesel vehicles because of heavy vehicle plates missing from the camera view of the passing vehicle and vertical exhausts.

Figure 3-3 shows the average emissions by model year and Figure 3-4 shows the approximate smoke contribution assuming:

- All vehicles have the same fuel consumption, and
- Gasoline vehicle particles are being measured in the same way as diesel smoke particles

Note again, however, that smoke emissions from some heavy vehicles and all vehicles with vertical exhausts are not included in the following series of charts.

Figure 3-1 Gasoline Vehicle Measurements

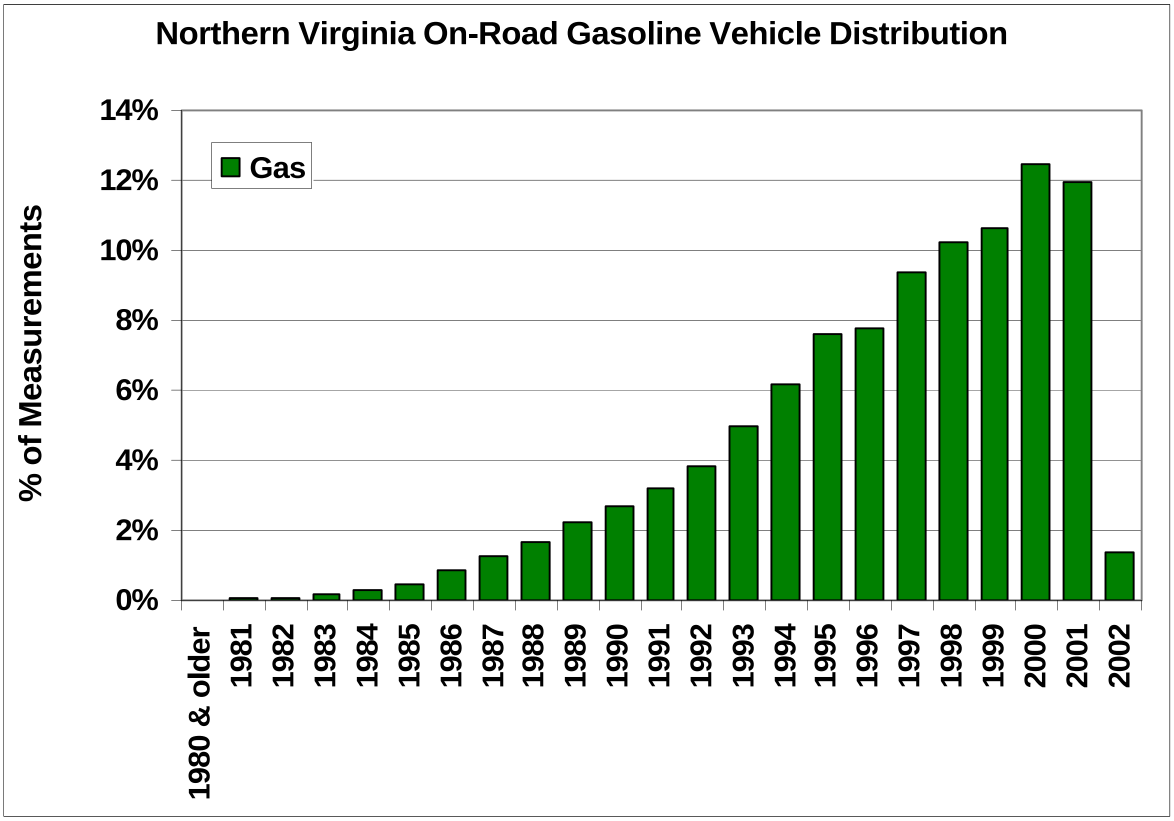


Figure 3-2 Diesel Vehicle Measurements

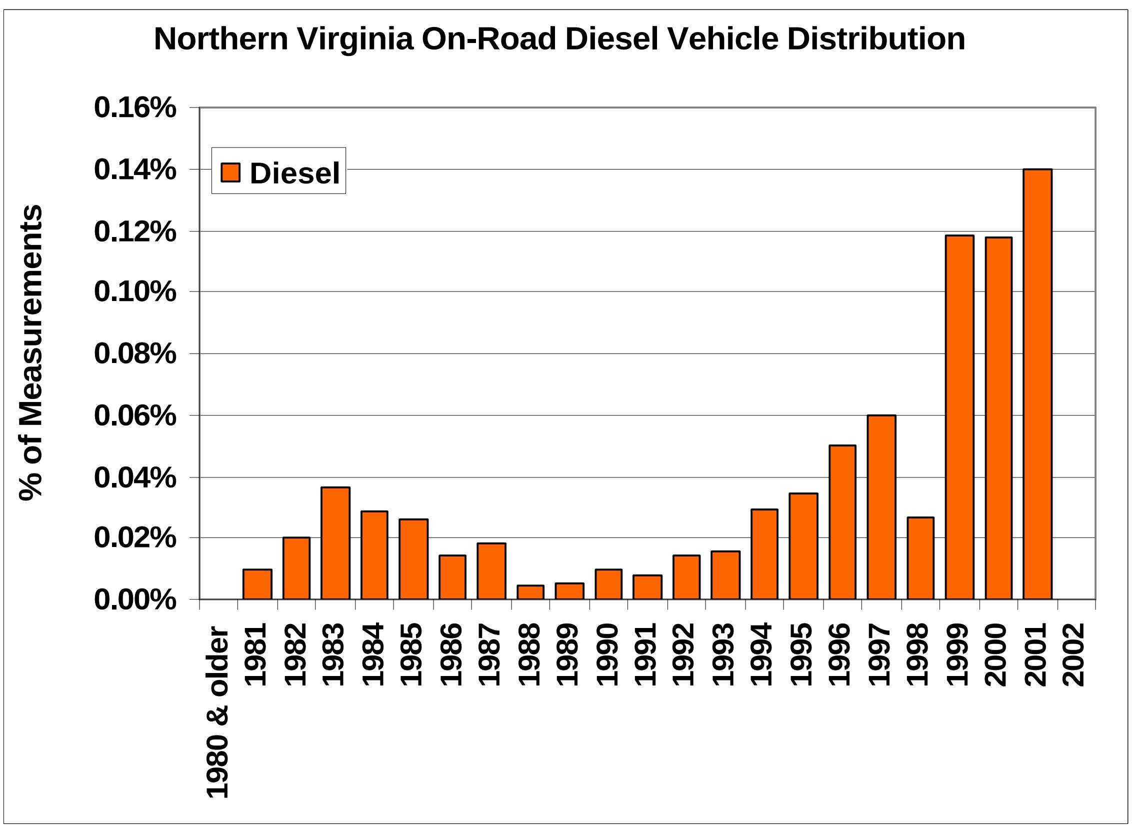


Figure 3-3 Average Smoke Emissions by Model Year

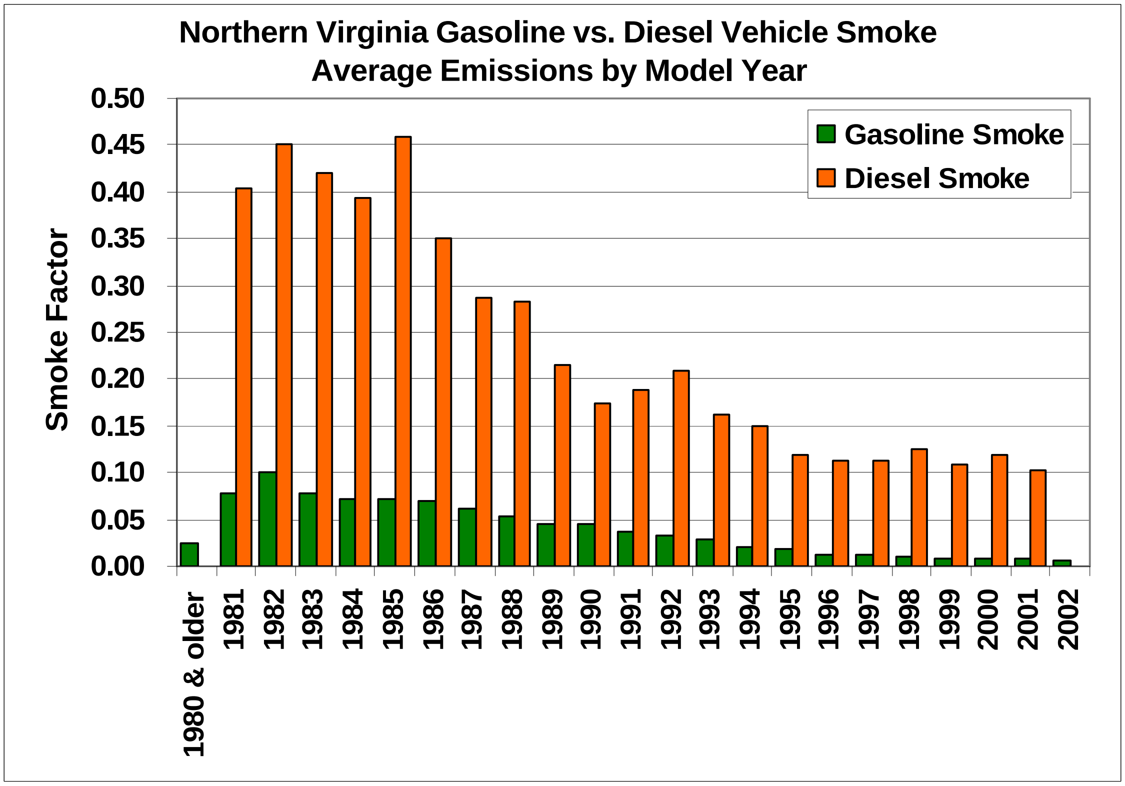


Figure 3-4: Smoke Contribution

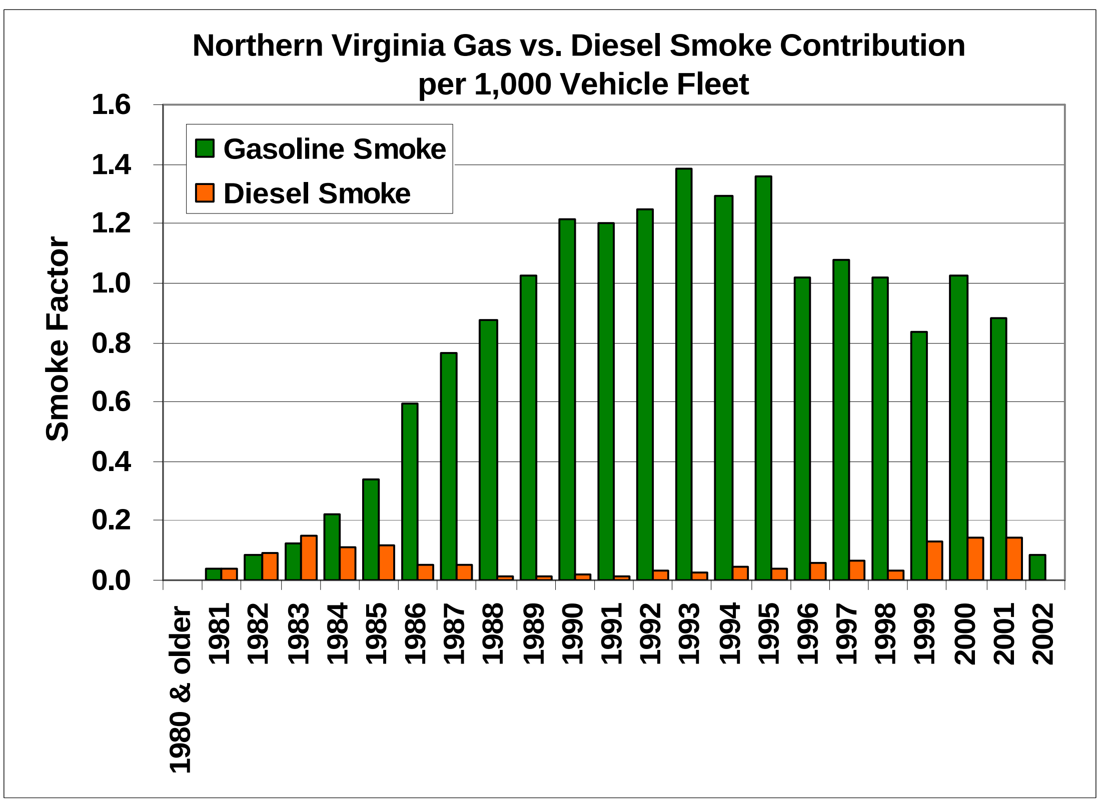


Figure 3-5 shows that gasoline vehicles subject to the I/M program have lower smoke emissions than non-I/M gasoline vehicles. The reductions are roughly consistent with the reductions in HC emissions shown in Figure 3-6.

Figure 3-5 I/M vs. Non-I/M Vehicles Average Smoke Emissions

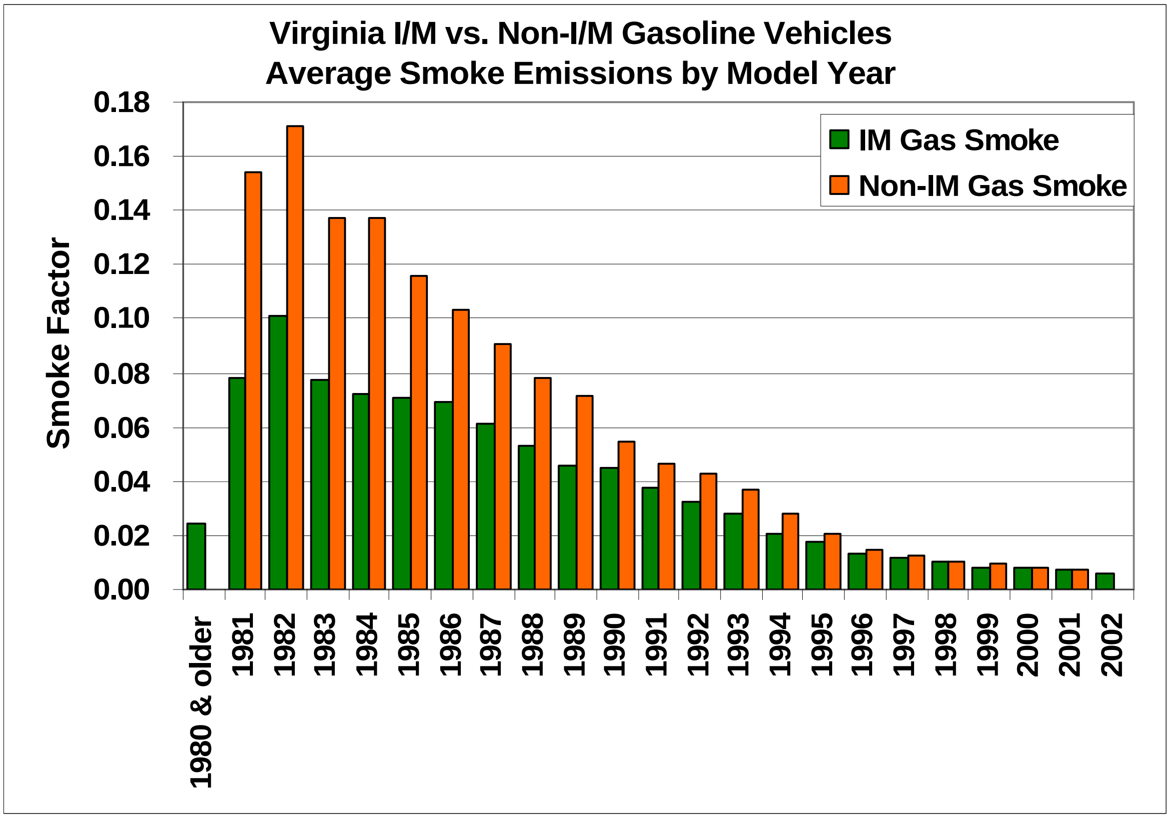
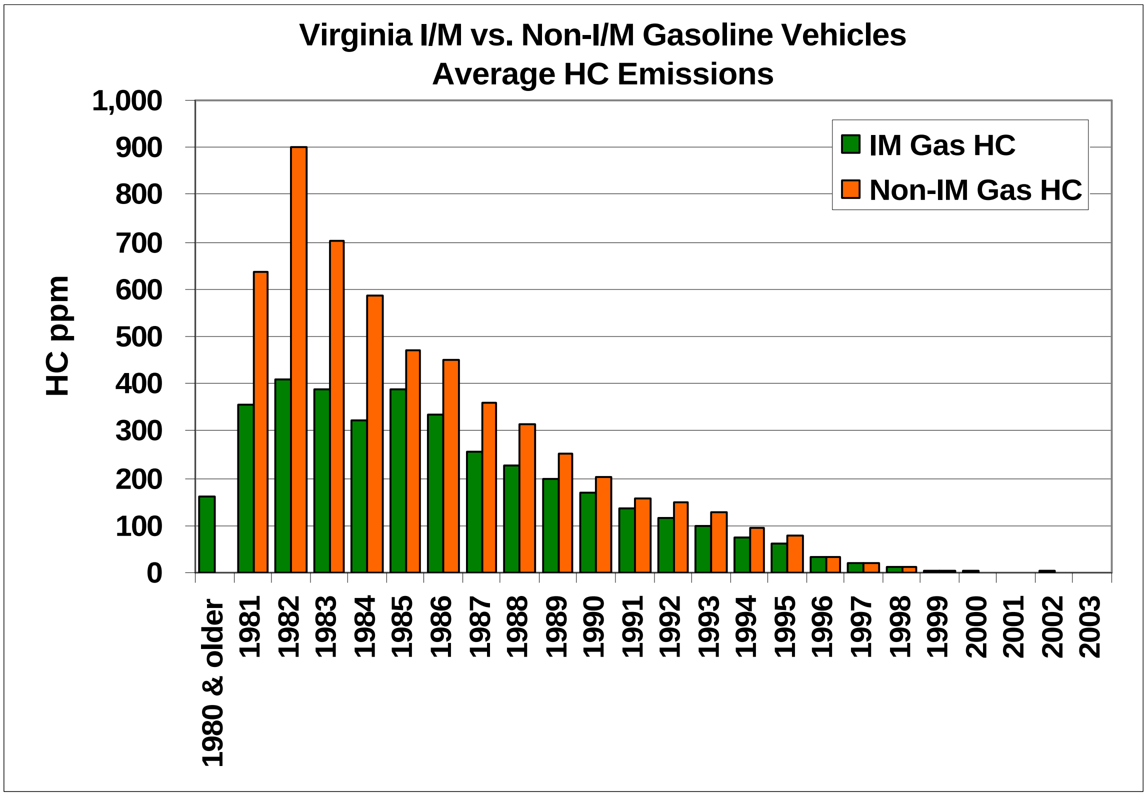


Figure 3-6 I/M vs. Non-I/M Vehicle Average HC Emissions



4. Distribution of Smoke Emissions within Model Years

The distribution of smoke within diesel vehicles shown in Figure 4-1 looks similar to a NOx distribution. Within gasoline vehicles the distribution, shown in Figure 4-2, is more similar to an HC distribution. The negative values in the gasoline vehicle distribution suggest a significant level of noise.

Figure 4-1: Smoke Deciles - Diesel Vehicles

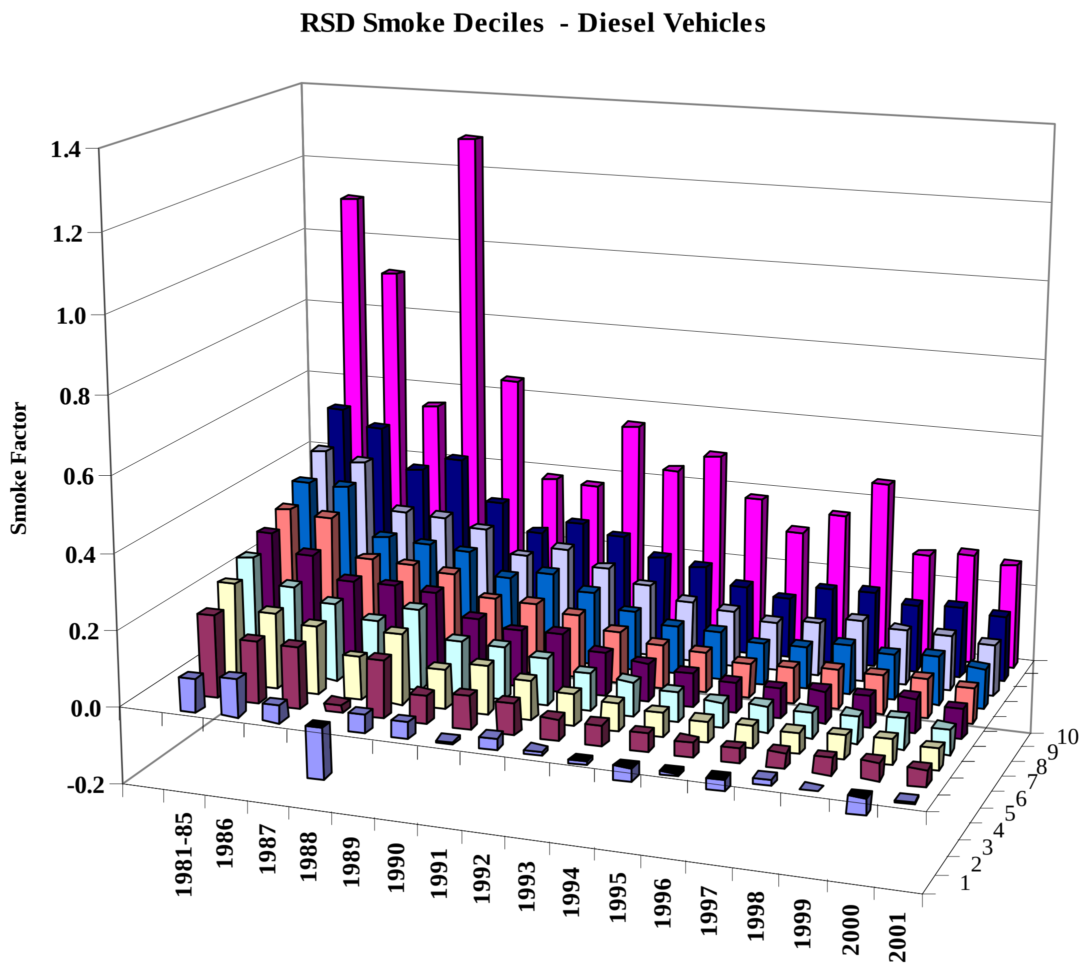


Figure 4-2: Smoke Deciles - Gasoline Vehicles